Cloth Based Biocompatiable Temperature Sensor

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I. SUMMARY AND MOTIVATION

Circular economy focussing on the reuse and recycling of materials is gaining significant interest these days as the concern for environment sustainability is increasing [1-3]. In this regard, printed electronics or green electronics is being promoted as alternative to conventional electronics, which requires several hazardous and toxic materials. However, there is lot to be done to align this emerging field with the requirements of circular economy [4, 5] and one way is to identify the waste materials and transfer them into a valuable products [6]. In this regard, integration of electronics in textiles is one of the attractive directions [7] and recently flexible devices like solar cells, sensors and electronics have been successfully integrated into textiles [8-12]. Here we present, a temperature sensor fabricated on biodegradable cellulose cloth. The fabricated cloth based temperature sensors shows a sensitivity of 30°C/Ω in the temperature range of 25-60°C.

II. ADVANCES OVER PREVIOUS WORKS

Moving towards textile based sensors, in our recent work, we developed a new textile based pH sensor for wearable applications particularly attractive for non-invasive monitoring of chronic diseases [11]. The textile-based electrochemical biosensors in [11] was fabricated using screen printing of graphite based sensitive electrode and Ag/AgCl based reference electrode on the cellulose substrate. However, for point of care analysis and for selective monitoring a multi-sensors are required [13, 14]. In which temperature is one of the important parameters to be monitored for various applications including healthcare and food quality [13, 14].

Various reports on the development of temperature sensor utilizing metallic, semiconducting and ceramics based temperature sensitive layers are available [15-18]. Although, due to the hazardous nature of the used sensitive layers along with multiple high cost processing steps makes them difficult to be employed for the circular economy. In this context, the cost effective, bio-compatible fabrication strategy utilized in the present work is beneficial and well-suited with the integration of various sensors (as shown in Fig.1), especially for the circular economy. Advancing further, this work demonstrates the low cost, facile and large area fabrication of textile-based temperature sensors utilizing drop casting of biocompatible conducting poly (styr-enesulfonate) (PEDOT: PSS) as a temperature sensitive material on the rough biodegradable cellulose cloth. The effect of variation in resistance of the sensor with temperature from room temperature (RT) to 60 ºC was systematically investigated. The change in the resistance of the sensor is attributed to the shift in the thermal energy leading to microstructural changes in PEDOT: PSS discussed in details [19, 20]. The fabricated temperature sensor in the present work

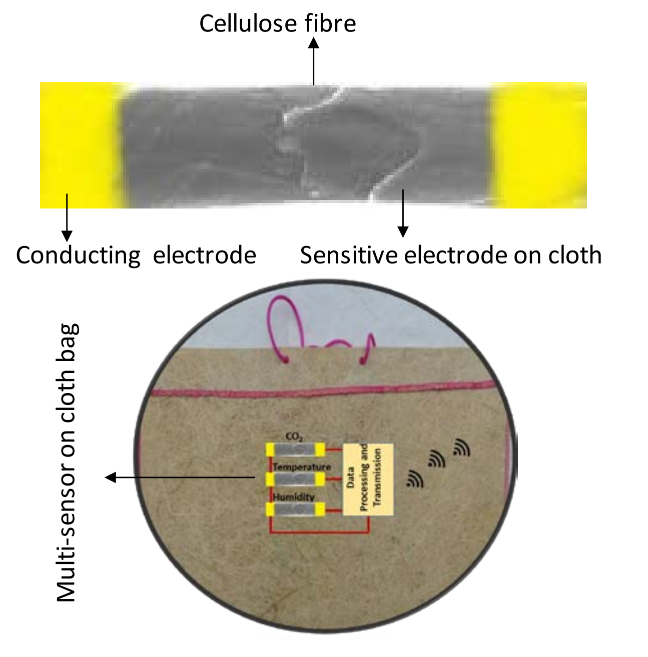

Fig. 1: PEDOT: PSS dropped on cellulose fibre for temperature sensor and its vision towards integration of sensors on cloth bag for wireless application.

demonstrates a sensitivity of ~ 30°C/Ω (0.8 % / ºC) and ~ 25 % variation in the resistance at 60 ºC from RT. The performance comparison of fabricated PEDOT: PSS based temperature sensors with the state-of-art reported in the literature is are summarized in Table I.

III. RESULTS AND METHODOLOGY

PEDOT: PSS has the advantage of ease of processing through diverse methods, such as drop coating, spray coating, spin coating and ink-printing techniques [21]. Here, the PEDOT: PSS based conductive polymer was dropped on the top of cellulose/polyester blend-based cloth. The drop casting allows an easy way of depositing the sensitive material on the rough surface of cloth.

TABLE I. SUMMARY OF TEMPERATURE SENSORS

Sensitive Material	*Range of Temperature (ºC)*	*Sensitivity (%/ºC)*	*Ref.*
Ni Fibres	0 to 100	0.48	[22]
Gold	30 to 80	0.15	[23]
Carbon Nanotubes	30 to 45	0.13	[24]
PEDOT:PSS on Fibre	-50 to 80	0.48	[25]
PEDOT:PSS	RT to 65	0.8	**This Work**

After coating the electrode kept in an oven at 70 °C to remove the solvent. After drying a room temperature curable Ag paste painted on both end of the conducting fibres. This Ag electrode will be function as a conducting electrode (as shown in Fig. 1) for the two electrode based temperature sensor. The resistances variation of the sensor was measured in room temperature and by varying the temperature in the range of (25-60°C). For temperature, monitoring the sensor was kept on hot plate and measured resistance was recoded the system through a LabVIEW controlled program.

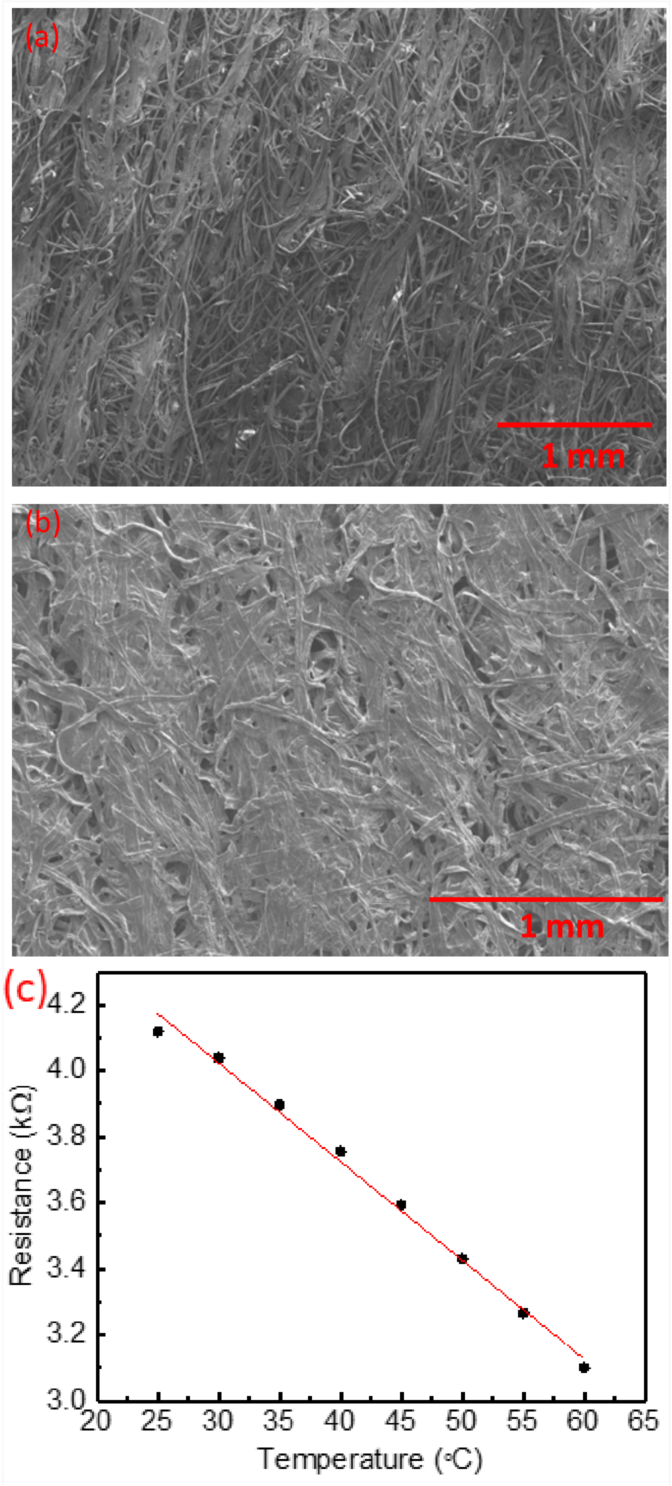

Fig. 2: (a)-(b) SEM images before and after PEDOT: PSS coating on cloth (c) variation in the resistance of electrode with temperature.

Due to the uneven and rough surface of the cloth (scanning electron microscopic image (SEM) of the cloth is shown in Figure 2a) drop casting is an easy and simple method of coating of the film on the substrate as compared to spin coating or other solution method. The excellent wet absorption capacity of the substrate is due to the presence of natural cellulose fibres content in it which improve the adsorption of PEDOT: PSS solution in the bulk of cloth substrate and strong interaction between PEDOT:PSS and polyester increase the adhesion between them. The SEM analysis shows that, after heating the PEDOT: PSS coated cloth the PEDOT: PSS is well distributed on the substrate and is shown in Figure 2b. The rough surface morphology of the film was obtained in the SEM analysis.

PEDOT: PSS is a p-type semiconductor and in which the resistance of the electrode decreases with increasing temperature due to the generation of holes in the valence band [20, 21]. When temperature is increasing due to thermal energy the electrons are excited in the valence band and it creates holes in the valance band. This decrease in resistance is a negative temperature coefficient of the resistance characteristics. Here a similar observation was found for the sensor. We varied the temperature from 25-60°C and we decrease in resistance as shown in Figure 2c. The observed sensitivity of the sensor is 30°C/Ω with a linear coefficient of 0.996. The sensor shows 0.8 % / ºC and ~ 25 % variation in the resistance at 60 ºC from RT. It was found that, the sensor exhibited almost a stable performance for fixed temperature. In addition to this we also observed that, the variation of conductivity of the PEDOT: PSS electrode also influences on the sensing performance. The conductivity of the electrode can be varied by adding dopant such as ethyl glycol, DMSO etc[21]. It was reported that, the length or area of the electrode also influencing on the sensing performance of the device [20]. A further study is required to investigate sensing performances in various conditions such as changing the conductivity of the electrode and area of the electrode.

Summarizing, a biocompatible temperature sensor has been fabricated on cellulose cloth by drop casting method for wearable and food quality applications. The PEDOT: PSS coated cloth shows a variation resistance with changing the temperature. The sensitivity of the sensor is 30°C/Ω in the temperature range of 25-60°C. As a future application a multi-sensor on cloth will be fabricated to simultaneously detect the temperature, humidity and CO_2 for food quality monitoring. The power requirement of the sensors online monitoring will be overcome by energy autonomous system [12, 26, 27].

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